مجلة تاريخ العلوم العربية

On the Construction of Ibn Bāṣo's Universal Astrolabe (14th C.) According to a Moroccan Astronomer of the 18th Century[1]

EMILIA CALVO

1. Introduction

Ḥasan b. Muḥammad b. Bāṣo was *faqīh* , *muwaqqit* and chief of the timekeepers in the great mosque of Granada. Ibn al-Khaṭīb emphasizes his great skill in the production of astronomical instruments and says that he was both an inventor and the author of treatises (*mustanbaṭāt wa tawālīf*). He died in 716 H. / 1316 A. D.[2]

Ibn Bāṣo wrote a treatise on the use of a device that he called *al- ṣafīḥa al-jāmiʿa li-jamīʿ al-ʿurūḍ* (universal plate for all latitudes) in 160 chapters. This treatise, completed in 1274, is preserved in several manuscripts extant in the Escorial (ms. 961), in the National Library of Tunis (ms. 9215) and in the Royal Library of Rabat (ms. 4288) .

A few abridgements of this treatise are also extant. The most remarkable of them is the one entitled *Nubḍa li-mā yataʿallaq bi-l-ṣafīḥa al-jāmiʿa*, " Note on the Universal Plate", the only known source which describes the construction of this plate, a topic which does not appear either in Ibn Bāṣo's treatise or in the other extant abridgements .

(1) This is a revised text of a communication presented in the *XVIII International Congress of History of Science* held in Hamburg and Munich in August, 1989.

(2) Cf. *Ibn al-Khaṭīb, al-Iḥāṭa fī akhbār Garnāṭa*, ed. ʿAbd Allāh ʿInān, vol. I (Cairo, 1973) p. 468; H. P. J. *Rénaud*," Notes critiques d'histoire des sciences chez les musulmans. I.- Les Ibn Bāṣo" *Hesperis*, 24 (1937) pp. 1 – 12 and " Additions et corrections à Suter", *Isis XVIII* (1932), p. 172 nº 381b.; G. *Sarton*, *Introduction to the History of Science*, (Baltimore, 1927 – 1931) vol. III p. 696; J. Samsó, *A propos de quelques manuscrits astronomiques des bibliothèques de Tunis: Contribution a une étude de l'astrolabe dans l'Espagne musulmane.*" *Actas del II Coloquio Hispano-Tunecino* (Madrid-Barcelona, 1972) I. H. A. C. Madrid, 1973 pp. 176 – 182 and E. *Calvo*, *les échos de l'oeuvre d'Ibn Bāṣo en Afrique du Nord . Actes du VII Colloque Universitaire Tuniso-Espagnol sur Le Patrimoine Andalous dans la Culture Arabe et Espagnole*. Tunis, 1991, pp. 65 – 79 .

* University of Barcelona.

2. *The Author*

The author of this summary is Abū-l-Rabīᶜ Sulaymān b. Aḥmad al-Fishtālī, an 18th century Moroccan *faqih* (he died in Fās in 1208 H./1794 A. D.)[3]. He knew the science of timekeeping and spherical astronomy (*ᶜilm al-mīqāt wa-l-taᶜdīl*) " with instruments and without them " and was Sulaymān al-Hawwāt's master[4]. Other data on his life are unknown .

We know several of al-Fishtālī's works like *Bughyat ḏawi-l- raghabāt* (What do those wish who have wishes) on the difficulties of Ṣibṭ al-Mārdīnī's[5] *al - Risāla al -Fatḥiyya* (Opening treatise), or *Sharḥ al-silk al-ālī fi muṯallaṯ al-Ghazālī*(Explanation of the thread of the Ghazālī triangle). He also wrote an abridgement of Ibn Bāṣo's treatise on the" universal plate for all latitudes " *(al-ṣafīḥa al-jāmiᶜa)* .

3. *Ibn Baṣo's Plate*

Ibn Baṣo's " universal plate for all latitudes " (Fig. 1) usually appears, among others, in western astrolabes, frcm the 14th century onwards, and its presence is relatively frequent. There are about twenty-five examples which are being catalogued[6]. Some were described in the past century but most of them have been unknown until recently . Although most of the examples are found in western astrolabes , as I say , some are included in eastern ones[7].

The treatise on the use of this plate is also known though it had not been studied in detail until the present[8]. It contains a description of the lines engraved on the plate and the way to use them. But there is not a sin-

(3) Cf. C. *Brockelmann*, *Geschichte der Arabischen Litteratur Supplementband II* (Leiden, 1938), p. 709; H. P. J. Rénaud, " Additions et corrections à Suter", *Isis* XVIII (1932) p. 183, n. 543; Khayr al-Dīn *al-Ziriklī*, *Al-aᶜlām* (Al-Qāhira, 1954 – 1959) 2nd ed., vol. 3, p. 182; *Al-Kattānī*, *Salwat al-anfās* lith. ed. (Fās, 1316 H.), vol. 3, p. 115; M. Makhlūf, *Shajarat al-nūr al-zakiyya*, (Cairo, 1931), p. 372 and R. *Kaḥḥala*, *Muᶜjam al-Mu'allifīn* (Damascus, 1957), vol. IV, p. 254.

(4) On this author cf. E. *Lévi-Provençal*, *Les historiens des Chorfa . Essai sur la littérature historique et biographique au Maroc du XVI au XX siècle*, (Paris, 1922), p. 336.

(5) *Muwaqqit of al-Azhar in Cairo* (fl. ca. 1460) Cf. H. *Suter*, *Die Mathematiker und Astronomen der Araber und ihre Werke.* Abhandlungen zur Geschichte der Mathematischen Wissenschaften, 10 (Leipzig, 1900) pp. 182 – 184 nº 445; C. *Brockelmann*, *Geschichte....* II p. 215 and H. P. J. *Rénaud*, *Additions...* p. 176, n. 445.

(6) Cf. D. *King*, *A Catalogue of Medieval Astronomical Instruments* : *Astrolabes* , *Quadrants and Sundials* . Preprints of the Institute for the History of Science. (University of Frankfurt). In preparation .

(7) Cf. E. *Calvo*, *La " Risālat al-Ṣafīḥa al-jāmiᶜa li-jamīᶜ al-ᶜurūḍ " de Ibn Bāṣo* . Edición traducción y estudio por ... (In press) I owe most of the information on the extant examples of this plate to professor D. King of the Institut für Geschichte der Naturwissenschaften (University of Frankfurt) who is preparing a catalogue of astrolabes and quadrants (cf. n 6).

(8) I have already finished an edition, translation and study of this treatise which have been the main theme of my doctoral thesis (cf. n. 7 above).

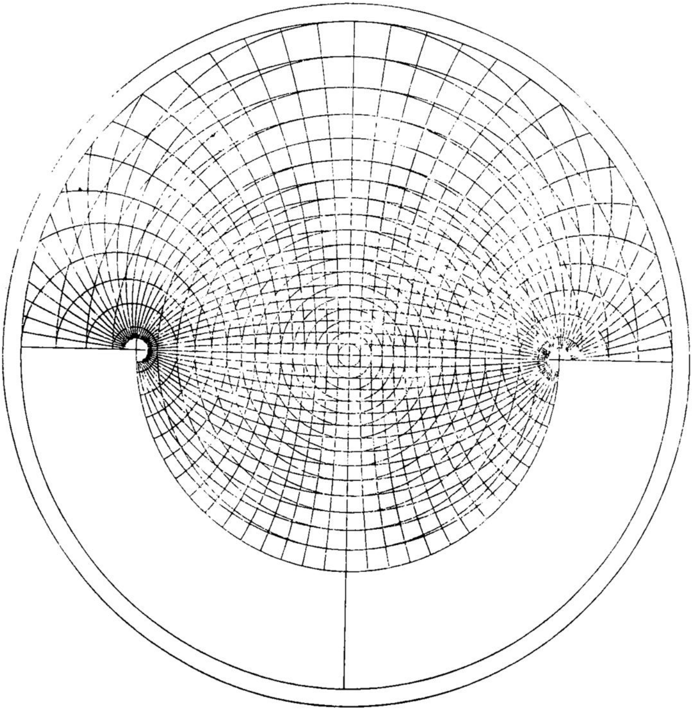

Fig. 1

gle chapter which deals with its construction. Therefore, the only source known to us on the construction of this plate is the aforementioned abridgement of Ibn Bāṣo's treatise by al-Fishtālī.

4. *The Manuscript*

Al-Fishtālī's abridgement is extant in manuscript 1009 of the Royal Library in Rabat (fols. 16v. – 19v.). The pages have 24 lines each . The writing is in the Maghribi script. The text is divided into five chapters and each one of them into one or more sections, in which al-Fishtālī basically explains *mīqāt*[9] matters . These chapters are preceded by a preface in which

(9) On this matter cf. *King mīqāt* in the *Encyclopédie de l'Islam* 2, t. 7, pp. 27 – 32.

al-Fishtālī ascribes the invention of this plate to Ibn Bāṣo who is identified as " al-Zubayr's master "[10] .

5. *Contents*

As for the contents of the *Nubḏa*, the first chapter describes the construction of the plate, as I have mentioned above. The second chapter gives the names of the lines drawn on the plate. The third chapter is divided into three sections : how to determine the arc of the day and night, how to calculate the arc rotated by the sphere and how to place the degree of the sun, according to its altitude, on the plate. The fourth chapter is divided into four sections: how to determine the azimuth of the sun or a star, its rising and setting amplitudes, half of the *faḍla* (difference between half of the day arc and 90 degrees), and how to calculate the meridian altitude of the sun or a star. Finally , in the fifth chapter, there are four sections devoted respectively to transformations of coordinates, the calculation of the solar altitude at the time of the *ẓuhr* and *ʿaṣr* prayers, the altitude of a star at the end of twilight and at the beginning of dawn, and how to determine the four cardinal directions and the azimuth of the *qibla.*

6. *The Construction of the Plate*

As I have mentioned above, this matter is dealt with in the first chapter of the paper. There is no drawing in the text to illustrate the different steps followed in the construction of this plate.

For its fabrication the author recommends brass or another similar metal, from which a smooth piece should be obtained. First, al -Fishtālī draws a circle (AC A'C' , Fig. 2) with an arbitrary radius , and on it two perpendicular diameters, AA' and CC'. The intersection of these two diameters with the aforementioned circle determines the four cardinal directions: point A corresponding to the south , point A' to the north , point C to the east and point C' to the west of the plate. This first circle drawn corresponds to the tropic of Capricorn.

After that he divides the southeast quadrant into fifteen arcs of six degrees each . The distance AE on quadrant AC equals the obliquity of the ecliptic (he adopts the value of 23;30° for it) and arc AE is called *qaws al-mayl* (declination arc) . Then, a straight line between points E and C' is drawn. The intersection of EC' with diameter AA' determines point P. Next, another circle, with a radius equal to the distance OP is drawn. This second circle is concentric with the first one and it represents the equator.

(10) According to Rénaud, he could be a disciple of Ibn Bāṣo's whose name is Abū Muḥammad al-Zubayr b. Jaʿfar b. al-Zubayr. On this author cf. C. *Brockelmann*, *Geschichte... II*, p . 1025, n. 88; H. P. J. *Rénaud*, " Notes critiques d'histoire... p. 2, n. 1; H. *Suter* , *Die Mathematiker und Astronomen ....* , p. 201, n. 513. *Al-Zubayr* is the author of another work entitled *Taḏkira ḏawi-l-albāb fi 'istifā' al-ʿamal bi-l-asṭurlāb.*

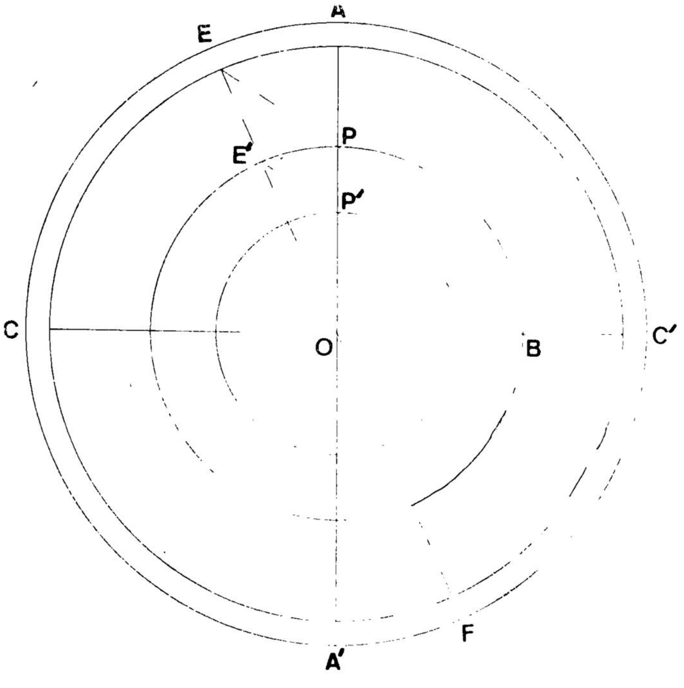

Fig. 2

Afterwards, we draw diameter EF which is used as an auxiliary line (*al-quṭr al-khafīyy*, hidden diameter). The intersection of diameter EF with the equator determines point E'. The arc E'P equals also the obliquity of the ecliptic. Then we join point E' to B, the intersection of diameter CC' with the equator. P' will be the intersection of E'B with diameter AA'. Finally, we draw a third circle, with a radius equal to OP', concentric with the other two and which corresponds to the tropic of Cancer. The construction procedure up to this point is the same as the one usually employed in standard astrolabe plates[11].

(11) Cf. H. *Michel*, *Traité de l'astrolabe*, (Paris 1947) p. 47 ss.; S. *García Franco*, *Catálogo crítico de astrolabios existentes en España*, (Madrid, 1945) pp. 70–71 and R. *Martí* and M. *Viladrich*, " En torno a los tratados hispānicos sobre la construcción de astrolabios hasta el siglo XIII " *Textos y estudios sobre astronomía española en el siglo XIII*, (Barcelona, 1981) p. 81.

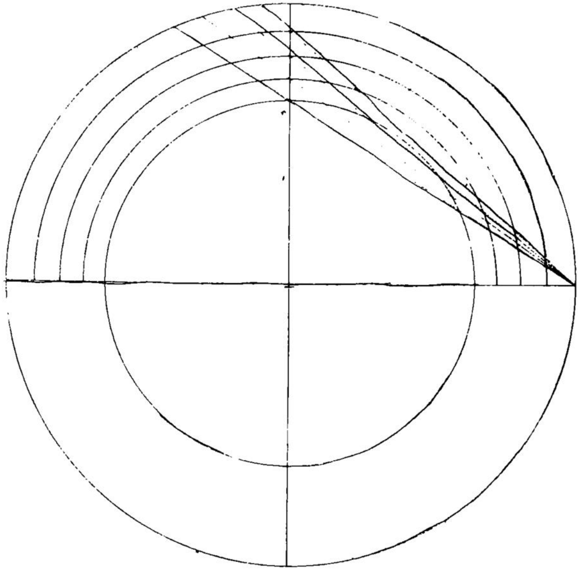

Fig. 3

Once these three circles are traced , and following the aforementioned procedure , we draw three concentric semicircles on the southern half of the plate, between the equator and the tropic of Capricorn using the six degree divisions on the declination arc AE (Fig. 3) . All these semicircles are the projections of the corresponding declination parallels (*anṣāf dawā'ir al-mayl*).

Next we divide the circle of the equator into arcs of six degrees each and draw the northern declination parallels (*al-madārāt*) following the same standard procedure and using the six degree divisions on the southeast quadrant Fig. 4). The number of *madārāt* will be, therefore, fifteen, including the equator and the tropic of Cancer . Al-Fishtālī says that they go from 0° to 90° and identifies them with *al-muqanṭarāt* for a 90° latitude in which the sphere turns " like a millstone " (*raḥawiyy*[an]) , that is to say,

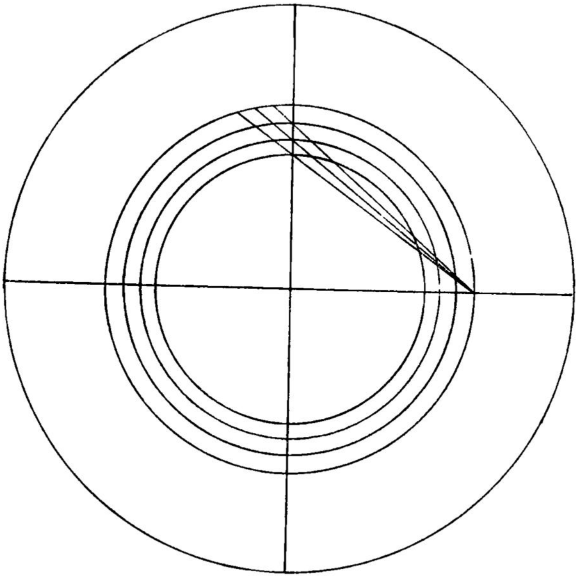

Fig. 4

parallel to the horizon[12]. The north pole is also the zenith and the south pole the nadir .

Minimum instructions to draw the horizons follow in our text . To obtain them, we draw as many arcs of circles as we want horizons (Fig5). Its number is the same as the number of parallels to the equator drawn before. There is no specification as to the way to find the centres of these circles. The only indication given is that the centres of all these horizons have to be placed on the north-south diameter (in the southern half for the northern horizons and in the northern half for the southern ones). Each of them has to be determined by three points (Fig. 6), two being the same for all horizons: points east and west on the equator. The third point is

(12) The term *raḥawiyy* is usually employed by other astronomers to express the motion of the sphere at the poles. Cf. for instance in Abū-l-Rayḥān *al-Bīrūnī*, *Kitāb al-tafhīm li-awā'il ṣinā*ᶜ*at al-tanjīm* (*The Book of Instruction in the Elements of the Art of Astrology* . (London, 1934) p. 140.

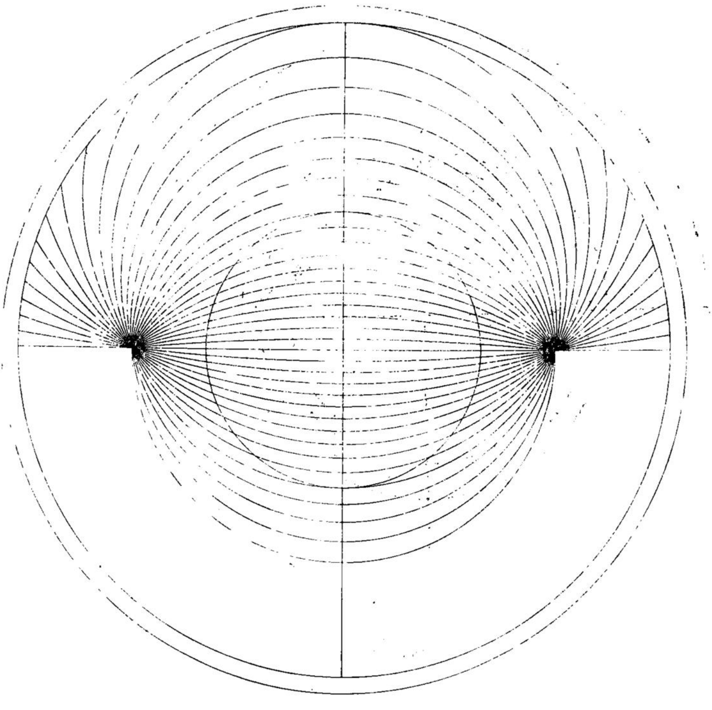

Fig. 5

different for each horizon : it is the intersection of the diameter (*quṭr*)[13] with the parallel the declination of which equals the colatitude corresponding to the horizon we want to draw. In the figure, the horizon is determined by points E and W and also by point P corresponding to the intersection of the parallel ROPQ with diameter EW.

Finally, the procedure for drawing the arcs (*qisī*) is described . This description is also very short. The author specifies that their centres have to be placed along the diameter[14] and that every one of them has to be

(13) It should be the north-south diameter but it is not so indicated in the text.

(14) It should be the east-west diameter but, as in the preceding case, it is not mentioned in the text .

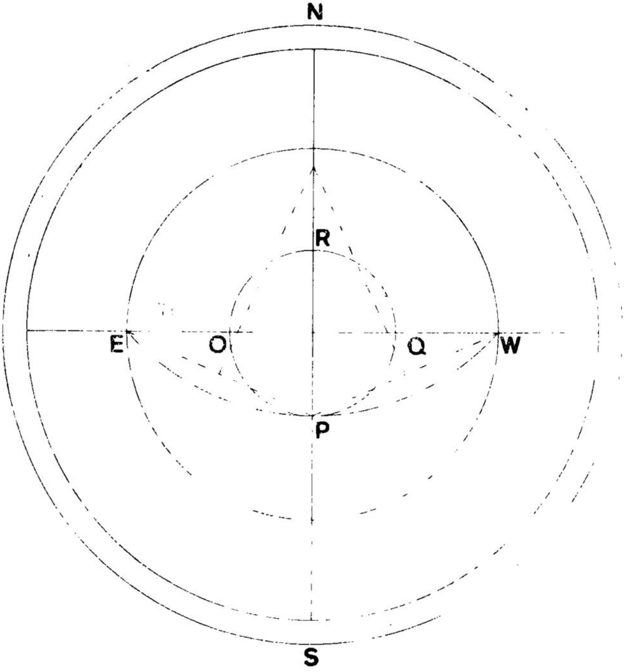

Fig. 6

determined by three points (Fig. 7): two of them are two six degree divisions of the equator equidistant from the east or west points of the equator. The third point is determined by the intersection of the east-west diameter with the parallel the declination of which equals the angular distance between the east or west point and the two six degree divisions used to draw this arc. In the figure, the arc of the equator MW equals the arc NW. Their value is also the declination value of the parallel RSTU. The three points which determine the arc are M, N, and T

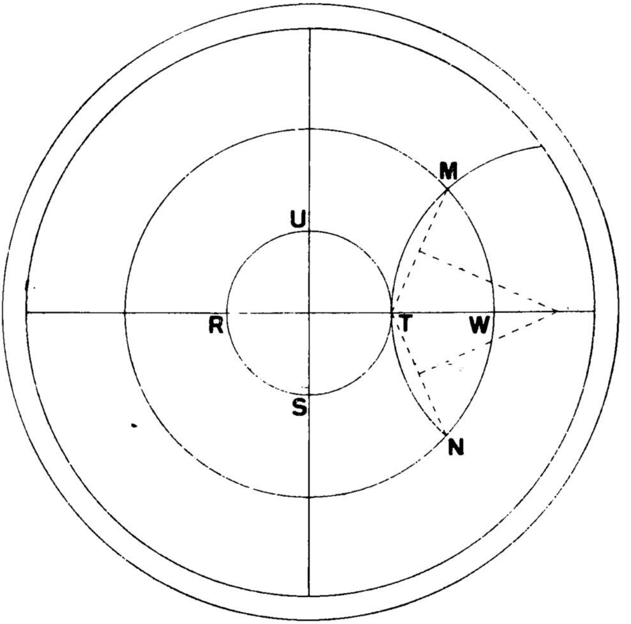

Fig. 7

The arcs (*qisi*, cfr. Fig. 8), which are also called " horizon divisions" (*ajzā' al-ufuq*), are employed to change the coordinate system (horizontal into equatorial and conversely) by a rotation equivalent to the colatitude of the place.

Al - Fishtālī considers the *horizons* as the projections of vertical circles corresponding to the two poles of the horizon of two places located on the equator and the longitudes of which , counted from the western meridian, are 0° and 180° respectively , whereas the arcs are circles of altitude (*al-muqanṭarāt*) corresponding to these two places.

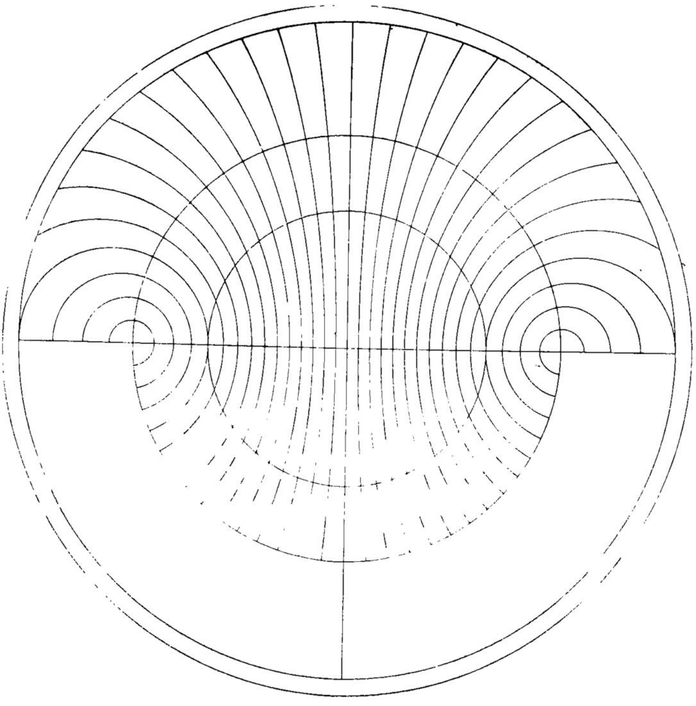

Fig. 8

Finally, our text gives not very clear instructions as to how to graduate the plate . The information we can gather from Ibn Bāṣo's text and the extant instruments show that the graduation of declination parallels appears on the northern half of the north-south diameter, between the equator (0°) and the centre of the plate (90°) for the northern parallels and between the equator and the tropic of Capricorn for the southern ones. As for the horizons , they are also graduated on the same diameter but in its southern half and with their latitudes increasing from the centre (0°) towards the equator (90°) . The graduation of the arcs appears on the space between them on the northern half of the equator and that of the semicircles of southern declination appears once again on the east-west line.

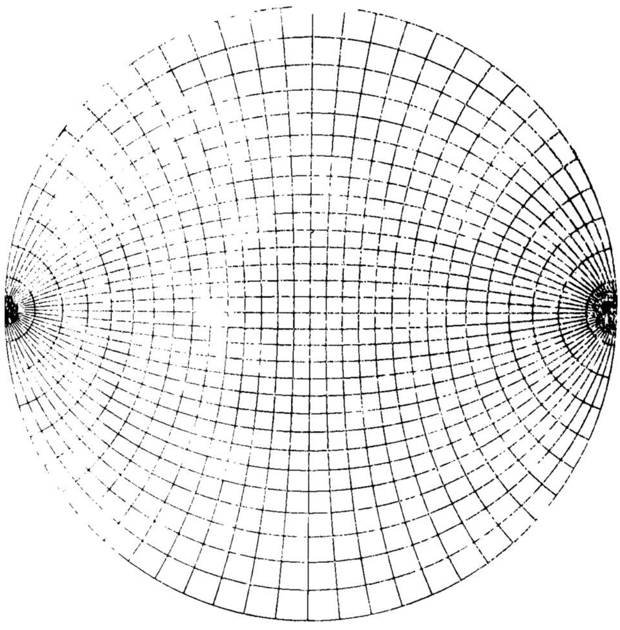

Fig. 9

7. *Conclusions*

After having followed the construction process described above we can see that the diagram formed by the super position of horizons and arcs in the sector comprised between the equator and the pole, obtained from a standard polar stereographic projection, is identical to the one we find on the plate of ᶜAlī ibn Khalaf's universal astrolabe or on *al-Zarqālluh's saphea* (Fig. 9)[15]. Those two later diagrams are obtained, however, from an

(15) Millās Vallicrosa saw these similarities when he described the general plate in the astrolabe of Tetuan but his interpretation of this plate was closer to the *azafea* than it really is. Cf. J. M. *Millás*, " Tres instrumentos astronómicos árabes de los museos de Tetuán y Madrid ". *Al-Andalus*, 12 (1947) págs. 49 – 55. Especially pp. 52 – 53. There is an interpretation in the same way in S. *García Franco*, *Catálogo crítico de astrolabios*.... p. 178 .

equatorial stereographic projection. In this respect we should remember that the procedure for the transformation of coordinates with this instrument (by a rotation equal to the colatitude of the place), is usually employed when using Ibn Khalaf's and al-Zarqālluh's instruments, but not with astrolabes. But, in the prologue to his treatise on *al-ṣafīḥa al-jāmiʿa*, Ibn Bāṣo feels obliged to state the independence of his plate from al-Zarqālluh's *ṣafīḥa*, possibly because he was aware of the influence exerted by this instrument on his own work. It is quite evident that Ibn Bāṣo made a re-elaboration of the principles that structured the *ṣafīḥa*, giving it a new point of view and, therefore, new possibilities of use. In the following centuries, some astronomers adopted that idea and reelaborated it in different ways. The results were some curious instruments in which polar and equatorial stereographic projections were combined in order to obtain the advantages of both systems. We find this kind of instrument not only in the Islamic world, but also among those made in Europe between the XIV th and the XVIIth centuries.

8. *Arabic Text*

The Arabic text included in this paper consists of an edition of the first chapter of al-Fishtālī's abridgement. Some copyists' errors have been corrected, and the readings of the text are given in the footnotes. Some words have been added between brackets to make the text clearer.

الفصل الأوّل : في كيفية وضع الخطوط والدوائر التي فيها

فأقول إذا أردت وضع الصفيحة الجامعة فتخيّر جسداً أملس صلباً مستوياً من نحاس أو غيره وأدر فيه حسب اختيارك دائرة . ثمّ أقم على مركزها قطرين على زوايا قائمة وتجعل على ملتقى أحدهما مع المحيط زيادة تدخل في الكرسي وفيه نقطة الجنوب وفي مقابلتها من المحيط نقطة الشمال والتي في يمينها منه نقطة المشرق والتي في يسارها نقطة المغرب . فانقسمت الدائرة بحسب ذلك أرباعاً . ثمّ اقسم الربع الجنوبي الشرقي ص جزءاً أقساماً سداسية أو كيف ما شئت واحسب من نقطة الجنوب في الربع قدر الميل الكلّي كج ل وعلّم هناك علامة . ثمّ ضع حرف المسطرة على العلامة ونقطة المغرب من المحيط وعلّم على ملتقى حرفها مع قطر الجنوب والشمال [علامة ثانية] . ثمّ (17 r) افتح البركار بعدً[ا] بقد[ر] هذه العلامـــة على المركز وأدر عليه دائرة ثانية داخلة هي مدار الحمل والميزان . ثمّ ضع حرف المسطرة على ملتقى نصف القطر الخفيّ ونقطة المغرب من دائرة الحمل والميزان وعلّم على ملتقى حرف المسطرة مع قطر الجنوب والشمال أيضاً علامة . ثمّ ضع احدى رجلي البركار بالمركز والأخرى بالعلامة وأدر

دائرة ثالثة في الربع بقدر الميل الكلّي داخلها هي مدار رأس السرطان . ثمّ أقسم قوس الميل من دائرة الجنوب أقساماً سداسية أو كيف ما شئت لاستخراج دوائر الميل في ناحية الجنوب . إذا فعلت ذلك فضع حرف المسطرة على نقطة المغرب من الدائرة وعلى قسم من أقسام الميل وعلّم على ملتقاهما من القطر علامة وهكذا إلى انتهاء العلامات . ثم [ضع] احدى رجلي البركار على المركز والأخرى باحدى العلامات التي على القطر وأدر أنصاف الدوائر بقدر العلامات من خطّ المشرق إلى خطّ المغرب في ناحية الجنوب فتحصّل دوائر الميل . ثمّ تقسم دائرة الحمل والميزان بثلاثمائة وستين جزءاً أقساماً سداسية أو كيف ماشئت .

فإذا أردت وضع المدارات فضع حرف المسطرة على قسم من أقسام الربع الجنوبي الشرقي من دائرة الحمل وعلى نقطة المغرب فيها وعلّم على ملتقاهما مع القطر علامة ولا زلت تفعل هكذا إلى تمام أقسام الربع . ثمّ ضع احدى رجلي البركار في المركز والأخرى على احدى العلامات من القطر وأدر دائرة تامّة وهكذا إلى انقضاء العلامات وبه تحصّل المدارات وغايتها 90 وهي في الحقيقة مقنطرات لعرض ص̅ حيث يدور الفلك رحوياً ويكون القطب الشمالي في سمت الرأس والجنوبي في سمت الرجل .

وأمّا دوائر الآفاق والقسي فحصّل الصفيحة في لوح العمل تحصيلاً محكماً بحيث لاتتحرّك[1] ويكون سطحها مساوياً لسطح اللوح . ثمّ أخرج قطرها في الجهتين[2] على سطح اللوح إلى أقصى[3] ماترى . فإذا أردت وضع الآفاق الشمالية فاحتلّ على أن تضع احدى رجلي البركار في القطر الجنوبي والأخرى بحيث تمرّ على ثلاث نقط وهي نقطة المشرق ونقطة المغرب من مدار الحمل والميزان ونقطة ملتقى احدى المدارات مع القطر في الشمال . وأدرها قطع دوائر تنتهي إلى محيط دائرة الجنوب في الجهتين أو دوائر تامّة داخلها ما عدا[4] الأولى فإنّها تنطبق على دائرة الحمل والميزان . وأمّا وضع الآفاق الجنوبية فعملها كالشمالية غير أن احدى رجلي الضابط[5] تكون على القطر الشمالي والنقطة الثالثة من النقط تكون على ملتقى احدى المدارات من القطر الجنوبي وهي لا تخرج كلّها من مدار الحمل بل تحصّل داخله[6] ما عدا[7] الأولى فتنطبق عليه

1. م. يتحرّك
2. م. الجيهتين
3. م. أقصا
4. م. عدى
5. م. الدابط
6. م. داخلة
7. م. عدى

وهذه الآفاق هي سموت قطبي أفق بلدين على خطّ الاستواء احداهما على منتهى العمارة في المغرب لاطول لها والأخرى على منتهاها في المشرق طولها قف .

وأمّا القسي فمنها شرقية ومنها غربية . فإن أردت وضعها فاحتلّ [على] أن تضع احدى رجلي (17 v) الضابط في القطر الذي تحتها والأخرى تمرّ على ثلاث نقط نقطتان منها من أقسام دائرة الحمل بعدهما عن [احدى] نقطتي المشرق والمغرب فيها بعد [واحد] والأخرى ملتقى احدى المدارات مع القطر في تلك الجهة مع الاتّحاد في البعد نسبة وتنتهي الى مدار الحمل في الشمال وان خطّ المشرق أو المغرب أو محيط دائرة الجدي في الجنوب وغايتها ض في كلّ ناحية . فافهم . وهي في الحقيقة مقنطرات لأفق الاستواء [للنقطتين] السابقتين[8] .

ولا بدّ أن تكون القسمة التي اعتبرنا في البعد بين هذه الخطوط متساوية لا باعتبار المدارات والآفاق والقسي . وتكتب أعداد المدارات والآفاق على القطر شمالاً وجنوباً إلى المركز و أعد[ا]د القسي فيما بينهما شمالاً على دائرة الحمل وأجزاء الميل على خطّ المشرق والمغرب .

8. م. السابقين